

Final Project Report

FIELD AND DATA MAINTENANCE OF THE FL-DEP BoMR VEGETATIVE FILTER STRIP RESEARCH FACILITY IN HOMELAND, BARTOW (FL)

Sponsoring Agency:
The Florida Department of Environmental Protection
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Executive Summary

The Florida Department of Environmental Protection/Bureau of Mine Reclamation (FDEP/BMR) has identified phosphorus released from reclaimed mining areas as a potential pollutant in Central Florida's Upper Peace River Basin. Best Management Practices (BMP), utilized on agricultural and other disturbed lands worldwide, have proven to be effective in the reduction of non-point source pollution. Vegetative filter strips (VFS), areas of dense vegetation designed to reduce transport of sediment and pollutants from surface runoff, have been widely recommended as a BMP by many state and federal agencies. Our recent project in the Peace River Basin (supported by the FDEP/BMR) demonstrated that under natural conditions, exposed sand tailings in reclaimed mining areas produce total phosphorus (TP) run-off loads higher than 100 lbs. per Acre (104 kg/ha), a very significant amount larger than most seasonal applications for horticultural crops in Florida. Furthermore, the In-situ study established that VFS are highly effective in reducing more than 95% of sediment and TP loads in surface runoff from these upland areas (sand tailings). The field results were used to successfully validate a computer model developed by the proposal PIs, VFSMOD-W, to optimize the filter size based on site-specific characteristics (% clay in refuse materials in the tailings, slope length and angle, vegetation types, design storms).

In April 2007, Florida Department of Environmental Protection (FDEP) – Bureau of Mine Reclamation (BoMR) and the University of Florida (UF) initiated the preparation of a short term contract (formalized in December 2007) to perform maintenance and data collection and processing at the vegetative filter strip (VFS) field research facility created in a previous project at BoMR's Homeland Field Office site. This report details the maintenance activities, data collection and processing methods and analysis of these data for the period of 2007 – April 2008. Comparison between the data obtained during 2007 – April 2008 and year 2006 (previous study) was performed in order to verify the trapping efficiency of TP, DP, sediments and water obtained in the previous study. Major project activities are summarized below:

1. The field setup had been designed for a project life of two years. Since the sites had been operational for 2.5 years at the beginning of this project, an initial overhaul/maintenance period was needed from April to July 2007 to replace equipment, redo temporary installations, replace part of the wiring and general maintenance.
2. Collection of water samples for chemical analysis, and raw (binary) data files was done at the field at least twice a month. A total of 24 field trips to the experimental sites were made. A total of 134 water samples were collected during 2007, along with supporting hydrological data, and 65 samples during January – April 2008 (175 through August 2008, outside the reporting period).
3. Field raw data files were regularly processed by parsing the contents, converting sensor voltage readings into final readings and exporting data to spreadsheet format. Processed data was immediately audited in order to isolate and identify possible problems in the system and guide the timing and content of the following field visit.
4. Maintenance of the field remote wireless data collection system was performed regularly during every field visit.

5. Replacement of field instrumentation components (i.e. damaged soil and flume probes, discharged batteries) and troubleshooting of potential equipment malfunction was done regularly, especially after major storm events.
6. The automatic water samplers were tested at least once a month to ensure the reliability of the system for the next rainfall event.
7. Control/removal of the weeds in the sand tailings source areas of the Hill Site was done at least monthly to ensure bare soil type conditions representative of the worst-case scenario.
8. Grass in the vegetative filter strips was mowed regularly to keep a prescribed maximum height of 15 cm.
9. Unusable data (due to equipment malfunction) were identified and reported as missed events.

Highlights of the preliminary data analysis include:

1. Generally high reduction efficiencies of runoff, sediment and TP were observed at both sites but this was much more variable for DP. This is expected since the filtering function of the dense vegetation relies on retardance of flow due to increase surface roughness at the filter, which produces a reduction in flow transport capacity of particulates (sediment and TP-apatite particles in sediment).
2. In contrast to TP, DP is removed mainly by infiltration during the short duration of a typical runoff event. Thus, higher DP reduction was observed for longer VFS that typically have more infiltration capacity than the contributing source areas. This illustrates the complexity of factors controlling filter efficiencies for different types of pollutants and local site conditions.
3. Due to the characteristics of site B (greater slope, area and rain) more sediments, Total Phosphorus (TP) and Dissolved Phosphorus (DP) are produced compared to Site A.
4. Sediment and TP removal for both periods, 2006 and 2007-Apr 2008, were above 0.9 with minor differences for each plot: VFS with lengths 4.1 and 5.8 m in Site A, and, 6.8 and 13.4 in Site B
5. Dissolved Phosphorus, DP, removal efficiencies were below 0.8 in most of the cases during 2006 and 2007-April 2008 periods (except for VFS of length 6.8 in Site B during the period 2007 – April 2008 that was the highest at 0.94). The lowest value obtained was 0.18 for VFS of length 13.4 m during the period 2007-2008.
6. For the period 2007 – April 2008, Vegetative Filter Strips flow volume removal efficiencies of plots Site B, and the 5.8 m long VFS of Site A were greater than 0.89; only VFS of length 4.1 at Site A had a lower efficiency, around 0.70, for flow volume reduction.
7. The results further support that under the conditions of the study relatively small areas dedicated to this BMP (at least 6 m) at the bottom end of the sand tailings slopes will likely suffice to retain particulate pollutant transport (sediment and TP) with runoff. More complex factors related specific soil characteristics at each site drive the DP removal efficiency, although in general this efficiency will be significantly lower than that for particulates.

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Background

Runoff non-point source pollution from phosphate mining areas poses a potential risk to ecosystems in many parts of the world. Mining sand tailings that still contain apatite (phosphate rock) shape the landscapes of reclaimed lands at the upper Peace River basin of Central Florida. Planting and maintenance of vegetation can be an economical and less labor-intensive method for reclamation of this and other mining areas. In particular, dense vegetation areas known as vegetative filter strips (VFS) have been widely recommended by many state and federal agencies as a best management practice (BMP) to control non-point source pollution from disturbed lands. VFS are designed to reduce transport of sediment and pollutants from surface runoff by deposition, infiltration, adsorption, and absorption. The sizing, placing and vegetation characteristics of VFS based on local characteristics are critical to achieve a desired runoff pollutant removal.

The Florida Department of Environmental Protection (FDEP)-Bureau of Mine Reclamation (BoMR) recently completed Peace River Cumulative Impact Study and resulting Peace River Basin Resource Management Plan both emphasize the need to analyze and control numerous sources of existing and potential pollution of the water resources of this important central Florida watershed. The department's Bureau of Watershed Management and Bureau of Mining and Minerals Regulation are cooperating in the assessment of pollutants, their sources, and formulation of Total Maximum Daily Loads (TMDLs) for the Peace Basin. Better understanding of the mechanics of pollutant transport, and development of models that will aid in the design of vegetative removal systems, will in-turn assist in the ultimate development of Best Management Practices for achieving TMDLs. As stated in the Basin Management Plan - Agency Action Items, the BoMR has a vested interest in assisting the University of Florida with related projects. Likewise, other state agencies like the Southwest Florida Water Management District, the phosphate mining industry, the agricultural industry, and the general citizenry of the Peace River Basin have a significant dependence on such research to assist in the protection of vital water resources.

In 2004, BoMR contracted with UF (DEP Contract SP633) to examine the following objectives:

- i) assess the potential surface runoff sediment and phosphorus (P) pollution from mining sand tailings in the upper Peace River basin;
- ii) investigate the efficiency of VFS in reducing P and sediment transport from the surface runoff of reclaimed mining areas;
- iii) study the relationship between the soil mineral source of P (apatite) and dissolved phosphorus (DP) concentration in runoff water;
- iv) simulate VFS phosphorus transport reduction from mining sand tailings in the Upper Peace River basin using the VFSMOD-W model.

To answer these questions, two experimental sites (A and B) containing 16 runoff plots (8 source+8 VFS) were selected and instrumented for this study (Fig. 1).

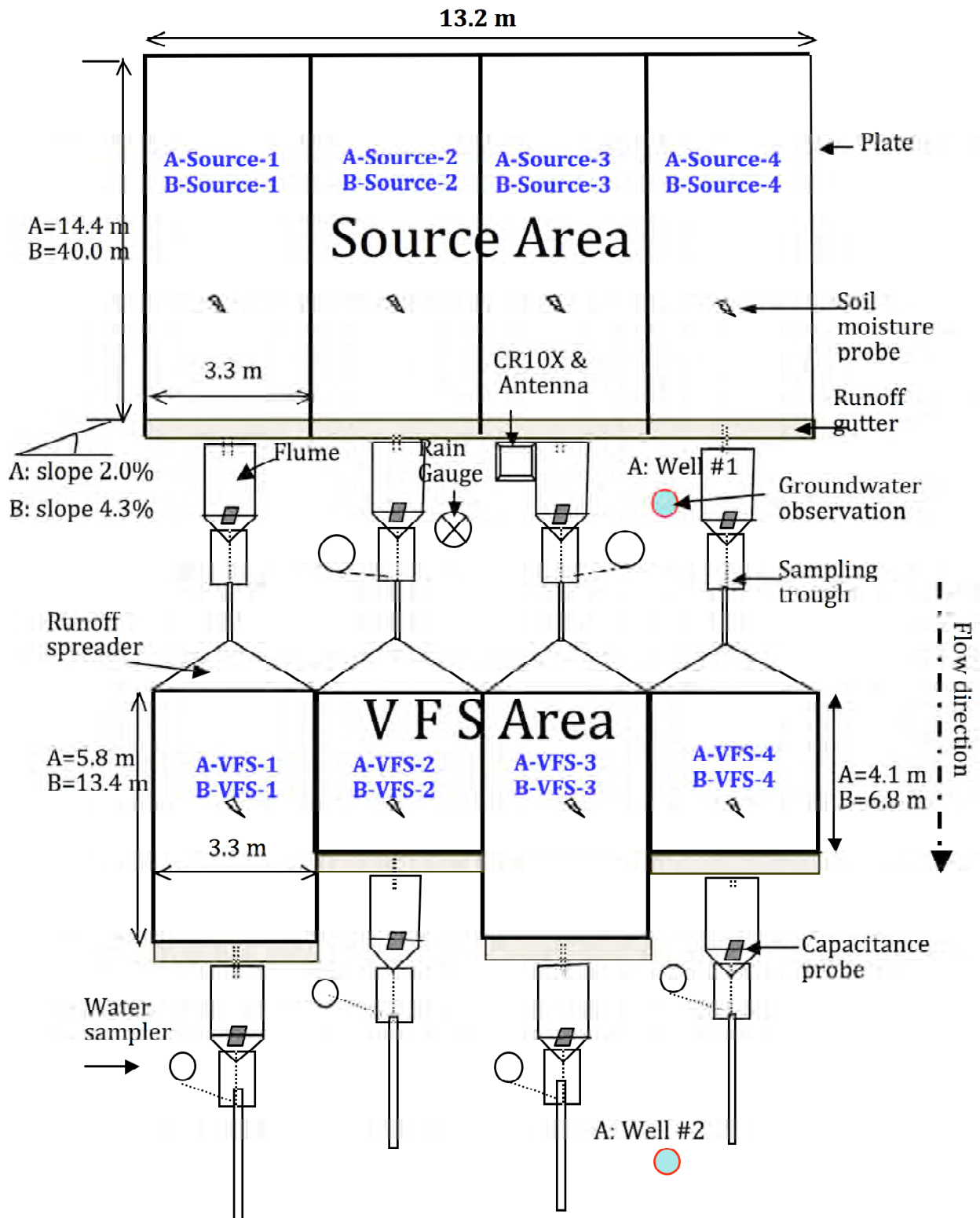


Figure 1. Schematic diagram of the experimental sites A (River) and B (Hill) in the Homeland Field Office, FL

The sites represent the range of conditions commonly found in source areas (sand tailings) at the region (i.e. slopes of 2-4.5%, slope lengths of 14-40 m, vegetation properties, and soil hydraulic properties). Source areas were maintained bare (no vegetation) to represent the

worst-case scenario conditions. VFS (vegetation mixture of 90% Bahia grass with Hairy Indigo, Cogon Grass, and Smutgrass making up the remaining 10%) of different flow-lengths (4-13 m) were installed downstream from the source areas. Rainfall intensity, source and VFS runoff flow rate and volume, sediment, and total phosphorus (TP) and dissolved P (DP) of discrete runoff water samples were measured from each natural runoff event at the sites during 2006 (Kuo, 2008; Muñoz-Carpena et al., 2006). Soil chemical analysis including soil pH, organic carbon (OC), TP, water soluble P, Mehlich-1 extraction, P sorption isotherms, TP in each particle fraction, and P fractionation are investigated. Runoff water samples were also used to determine relative stability of phosphate compounds and minerals in runoff. The numerical model VFSMOD-W (developed by the PI) was used to successfully predict overland flow and sediment trapping within the filter and was linked to a P transport algorithm developed based on experimental data to predict TP, PP, and DP fractions in the filter outflow. An advanced global inverse optimization technique is used for the model calibration process, and consideration to the uncertainty of the measured data was given.

Over the 2006 experimental and monitoring period, this effort successfully established a detailed database of runoff quantity and quality from sand tailings in the area, as well as the relative pollution reduction achieved with vegetative filters under these conditions. The main project findings are summarized below:

A) Phosphorous content of reclaimed sand tailings soils:

- An average value of 2.3 % of total phosphorus (TP) was found in surface soil samples of the reclaimed mining areas in the upper Peace River basin.
- Higher TP concentration was found in the finer soil particles than in the coarser particles.
- Phosphorus in sand tailings soils at the sites was in the form of apatite, as indicated by x-ray diffraction (XRD) and chemical fractionation.
- P dissolution and sorption studies supported the hypothesis that release of P from the soil was primarily from apatite dissolution rather than desorption from metal oxides that is more typical of soil of the region.

B) Runoff quantity and quality from mining sand tailings:

- Runoff was produced at the sites during relatively large rainfall events. A total 40 such events were recorded on the experimental sites during the year. Of these, around 60% of the total at each site produced sufficient runoff to be sampled. DP concentrations in runoff from source and VFS areas range from 0.4 to 3.0 mg/L, exceeding the EPA criterion of P concentrations (0.1 mg/L) discharging into a river.
- The slope, flow path length and soil permeability of the sand tailings source area conditioned the amount of sediment and P observed in surface runoff. The longer, steeper and less permeable source areas selected had a yield of 4.5 Tm/ha-year of sediment, 104 kg/ha-year of TP, and 2.21 kg/ha-year of DP. These numbers were significantly smaller for the flatter, shorter and more permeable site studied (240, 6.12, and 0.27 kg/ha-year sediment, TP and DP, respectively).

C) Efficiency of vegetative filter strips:

- Runoff volume, sediment, TP, and DP were reduced at least by 62%, 97%, 96%, and 66% with 6 m vegetative filter strips in these two sites.

- Power equations of the product of total runoff volume and peak flow rate for each runoff event were found to describe well the relationship between sediment yield and flow from the source areas.
- Runoff sediment concentration and runoff particulate phosphorus (PP) exhibit a strong linear correlation both at the source and VFS areas.
- The VFSSMOD model can predict hydrology transport accurately (Nash and Sutcliffe coefficient of efficiency, $C_{eff} = 0.60 - 0.99$) for all but small events likely due to large measurement uncertainty in the small events.
- A new P surface transport modeling component was developed that successfully predicts TP, PP and DP for the area. Good model predictions in runoff and sediment also result in good prediction of PP transport ($C_{eff} = 0.96$) since apatite exists almost evenly in sediment. Modeling DP considering release of P from apatite into runoff water results in better predictions C_{eff} (0.97) than in the case when dilution from rainfall is considered ($C_{eff} = 0.86$).

In **April 2007**, Florida Department of Environmental Protection (FDEP) – Bureau of Mine Reclamation (BoMR) initiated the development of a short contract with the University of Florida (UF) to perform maintenance and data collection and processing at the vegetative filter strip (VFS) field research facility created in the previous project at BoMR’s Homeland Field Office site. The Statement of Work (SOW) for the contract included two tasks to be developed through the contracting period. An extension of the work to include data through April 2008 was granted in July 2008. Table 1 summarizes the tasks and deliverables contracted in this project and reported herein.

Table 1. Project tasks and deliverables

TASK	DELIVERABLE
1. Research Site Maintenance	1.1 One (1) electronic copy of field maintenance report (electronic mail or CD-ROM in MS Word format) shall be submitted to the BoMR at the end of the work period.
2. Data processing and upload to the online database UF-HydroBase	2.1 Web access to the experimental data will be provided to the BoMR personnel along basic access instructions to HydroBase and a summary of the data stored in the system. This report will be incorporated in the Final Project Report.
	2.2 Final Report

Research Site Maintenance (Task 1.0)

Introduction

Field sites A (River) and B (Hill) were installed and maintained by UF from 2005 through April 2007. Maintenance and collection of data from these sites continued through this purchase order during winter 2008. Field visits were conducted by UF to test the equipment, clean up the site and replace faulty sensors and batteries. Data was downloaded and water samples (if any) were collected and sent to the UF’s NELAC-certified laboratory (UF/TREC, Homestead) for analysis. Remote monitoring of the field dataloggers was conducted at least once a week in combination with weather forecast monitoring. Additional field visits were scheduled if equipment malfunction was detected or a major storm (and subsequent runoff event) was registered on the sites. Continued data collection over the winter 2008 season aimed to improve the reliability of the results provided in the previous report (Muñoz-Carpena et al., 2006). Additional weather data was obtained from the BoMR HFO weather station.

Major field maintenance was scheduled during the period April – July 2007. This was necessary since the original field set-up was designed for 2 years duration but had already been in service for 2.5 years. Various temporary installations needed to be overhauled and equipment tested and replaced. Although this report only present results until April 2008, work has continued on site through summer 2008 (Table 2).

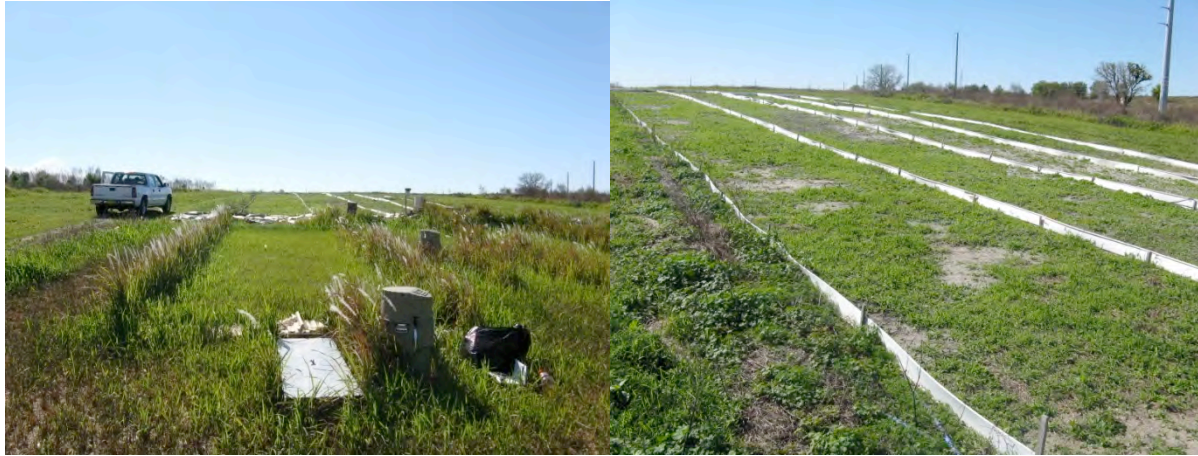
Table 2. Summary of field trips and samples collected to date.

Period	Field trips	Water samples collected and analyzed
Jan 2008– Apr 2008	19 (Feb 04; Mar 08; Apr 6,12,27; May 11,24; July 10, 30, 31; Aug 06,07,15,21,24; Sep 05,25; Oct 08,23)	134 [Feb (28), Apr (15), Aug (50), Sep (7), Oct (34)]
May – Aug 2008	12 (May 01, May 4, May 15, May 23, Jun 24, Jun 27, Jul 01, Jul 11, Jul 24, Jul 31, Aug 12, Aug 21)	175 (June 15, June 21, June 25, June 30, July 08, Jul 11, Jul 16, Jul 23, Jul 27, Jul 31, Aug 08, Aug 16)

During the initial scheduled maintenance the main problem in the River site (Site A) was related to failure of electronic devices (probes, data logger, and power supply). In the Hill site (site B), the main problem was the weed invasion in the source areas, especially at the beginning of the rainy season. A significant effort was invested in manually removing weeds to minimize site disturbance, combined with spot applications of contact herbicide. This was necessary to maintain the worst-case scenario conditions; since weeds in the source areas increase its infiltration capacity and controls the runoff sediment before it reaches the experimental filter strips. Local fauna (birds and rats) had also affected some electric and mechanical devices such as wires and the rain gages. Table 3 summarizes the maintenance tasks performed in each field site.

Table 3. Maintenance actions during the period April – July 2007.

Experimental River Site (A)				
Item Number	Affected component	Cause(s)	Failure Affects	Maintenance remarks/actions
1	Soil Probes	Unknown	Readings of soil moisture	Soils probes replaced Some wires were changed
2	Probes at flumes	Unknown	Readings of water levels in the flumes Spurious triggering water samplers (no water samples collected)	Same than Item 1
3	Samplers	Power failure	Collection of water samples. No runoff samples to be analyzed	Two solar panels were added to continuously recharge the field batteries during the day Batteries (three) replaced of a fixed schedule
4	Data Logger	Unknown	Storage of water levels on flumes, soil moisture and rain readings	Field data logger replaced
Experimental Hill Site (B)				
5	Source Area Surface	Weed invasion	Amount of runoff water and sediments that enter to the Vegetative Filter Strip located downhill. Soil Probes (malfunction)	Weed removal and control by mechanical and chemical (herbicides) means. Soil probes replaced.
6	Soil probes	Same than item 1	Same than item 1	Same than item 1
7	Probes at flumes	Same than item 2	Same than item 2	Same than item 2
8	Samplers	Same than item 3	Same than item 3	Same than item 3
9	Wires	Cut during mowing operation. Chewed by rats	Same than items 1 and 2.	Around 30% of the wires have been changed.
10	Rain Gage	Debris from birds	Rain gage blocked. Rain cannot be counted by the internal bucket system of the rain gauge.	A belt of spikes has been adapted over the tipping bucket rain gauge.



(a)

(b)



(c)



(d)

Figure 2. (a) & (b) Source area and VFS at hill on Feb 28 (2008), (c) Source area on March 13 (2008) at the Hill Site, and (d) source area at the River Site at any time of the year.

To ensure the worst-case scenario conditions the source areas were designed to be maintained bare (no vegetation at all times). Figure 2 shows the fast growth of weeds experienced at the Hill site. For instance, Hand removal of weeds and spot application of contact herbicide was done during the last week of January (2008). After a month, the source areas were completely covered again (Fig. 2a and 2b). Additional weed control took place the first week of March. By the second week of March the weeds were controlled, except for a small spot at the end of the source areas (Figure 2c). In contrast, Figure 2d shows that the source area on the River Site remained clean during all the year after receiving the same maintenance as in the Hill site.

Revised Field Standard Operating Procedure

With the experience gained after overhauling the system set-up during the scheduled field maintenance period, a revision of the field Standard Operating Procedure (SOP) was made. Two types of actions were revised.

a) Remote site management:

1. Weekly downloading and processing of the data via remote control access to the computer in Bartow.
2. Immediately following the data downloads, the maximum precipitation intensity (I_{30}) and the runoff volume in the flume are to assess equipment malfunction and if samples are ready to be picked-up after major storm events.
3. The battery voltage is also noted so fresh batteries can be carried to the field in the next trip as needed.
4. Weekly analysis of the soil moisture readings (probes) in the remote data download. If needed, replace them during the next visit to the experimental field site

b) Field maintenance:

5. Test the runoff probes in the field at least once a month to check that the triggering system of the water samplers works when the probes in the flumes detect water. In the case problems are detected, trouble-shooting and fixing this problem takes priority for that trip over regular maintenance tasks. To trouble-shoot the problem, the wires, the probes, the rain gage and the samplers need to be checked independently and as a system. If the problem cannot be resolved at the end of the day, then another visit to the experimental site has to be done during the same week.
6. Check if the amount of actual water samples collected in the field matches expectations according to the I_{30} and the runoff registered. If not, then proceed to test the entire system as described in the previous point.
7. Control/remove the weeds in the source areas of the Hill Site during each visit to the experimental sites.
8. Once a month, check if the six samplers of each system (River and Hill) are able to sampling continuously at the same time for at least 30 minutes, since every sampler has 24 bottle samples and the system can collect runoff water every minute (one minute per bottle).

Data processing and upload to the online database UF-HydroBase (Task 2.0)

Data from the previous research study was combined with newly available data collected since. This dataset includes sensor data (source and filter areas runoff flow rate, soil moisture, rainfall, groundwater elevation, water samples dates and times) and water quality data (EC, pH, sediment by particle size, total phosphorus, dissolved phosphorus). The combined dataset was converted to meet the database requirements. The resulting dataset was audited for consistency, errors and quality control. The final dataset will be uploaded into the HydroBase system, a web based database for hydrological research, for remote access, and basic statistics obtained. Details of the project data set and access to the HydroBase service are given in Appendix I of this report.

Tables II.1 – II.6 in Appendix II summarize precipitation, runoff, I_{30} , total load of Sediments, Phosphorus (TP) and Dissolved Phosphorus (DP) for the events of years 2007 and 2008 (January – April) for both field sites River (A) and Hill (B). Runoff is generally produced at the sites during relatively large events with intensities $i_{30} > 10$ and 14 mm/h for Sites B and A, respectively. Rain data were collected regularly from the River Site, except during August 2007 and the first weeks of September 2007 because the CR10 Data Logger randomly malfunctioned, and it had to be replaced.

Thirty three rainfall events were recorded in 2007 in the River Site, but only 19 ((55%)) produced an $I_{30} > 14$ mm/hr to produce runoff in this site. From those 19 events, 5 events occurred during the maintenance period and 5 in the period August-September, when the data logger failed (Table II-1). No significant rainfall event occurred in January, November and December 2007. In 2008 (January – April) five events with an $i_{30} > 14$ mm/hr were recorded. Three of them had an i_{30} between 14 and 16 mm/hr and the samplers did not get any water sample (Table II-2). The other two events ($i_{30} > 25$ mm/hr) collected water samples for phosphorus and sediment analysis.

The Hill site required the most maintenance work during the experimental period. Since data recording was intermittent as long as maintenance actions took place, the estimation of the i_{30} required the adaptation of rainfall data from sources other than the field rain gauge. Missing data was complemented with records from the Bureau of Mining Reclamation weather station at HFO and a local micrometeorological station less than one mile from the research sites (<http://www.wundergrund.com/weatherstation/WXDailyHistory.asp?ID=KFLHOMEL1>). It is important to mention that the minimum rainfall intensity recorded at the BoMR weather station was 0.01 inch (0.254 mm) every 5 minutes, which is more than the minimum value of rain that the field rain gauge resolves (0.1 mm). Based on this information, it was estimated that up to 54 rainfall events occurred during the year 2007 at the Hill site (Table II-2), but 38 of them had $i_{30} < 10$ mm/hr (68%). This means that only 16 rain events were expected to produce runoff at Site. However, 10 of these 16 events happened during the maintenance period April-July 2007 and when the system was not functional for water sample collection. For the six remaining events, the automated system, collected samples in 5 out of the six possible events. In 2008, seventeen events were recorded, but only four had $i_{30} > 10$ mm/hr. Only two events produced enough runoff for the automatic samplers to take a usable sample for analysis (February 23 and April 6). Additional data and samples, beyond the scope of this project, is being collected through the end of Summer 2008 and will be used for ensuing publications and model testing

Tables II-5 and II-6 in the Appendix II show the results for the water samples collected in each rain event for sites A (River) and B (Hill) respectively. We are pending to get the results of

TP and DP for the month of March and April 2008 from the UF Soil Chemistry Laboratory in Homestead. Data are reported as load of sediments (Sed) , total phosphorus (TP) and dissolved phosphorus (DP) in grams. Source areas 1 and 4 (numbered from left to right looking upslope in the field site, Fig. 1) are always reported as “NA” (not available) because there are no water samplers installed there. A total of six samplers are installed per field site (each site has 8 plots). This means that potentially, for a good rain event, up to six series of water samples (2 from source areas and 4 from vegetative filter strips) could have been monitored.

Table 3 shows a summary of balances of water, sediments, TP and DP during the period of analysis January 2007 – April 2008. Due to the characteristics of site B (greater slope, area and rain) more sediments, TP and DP are produced here compared to Site A. Again, at site B values of variables related to rain (rainfall duration, total rainfall and i_{30}) may be underestimated because they are obtained from 3 different sources (gauges) during part of the period. However, we can observe from Table 2 that more runoff and pollutants (sediments, TP and DP) are produced in Site B.

Table 4. Summary of rainfall-runoff events collected at sites A and B with corresponding ranges of runoff volume (V), peak flow rate (Q_p), initial soil water moisture (θ_i) and loads of sediment, TP and DP during the period January 2007 – April 2008.

Site	All rainfall events				Runoff events only											
	n	Rainfall duration (min)	Total rain (mm)	i_{30}^+	n	Rainfall duration (min)	Total rainfall (mm)	i_{30}^+	Plot*	N	V (m ³ /ha)	Q _p (L/s)	θ_i %	Sediment (kg/ha)	TP (kg/ha)	DP (kg/ha)
A	51	20-631 (9.1,2.9) [#]	0.7-62.8 (5.4,2.1) [#]	0.7-56 (0.3,1.2) [#]	15	20-309 (6.1,2.3) [#]	7.3-41.5 (0.7,0.9) [#]	14.6-56.0 (-0.6,0.6)	A-Source	15	0-106.5	0-1.3	0.01-0.09	6.38	0.59	0.09
									A6	13	0-72.5	0-0.4	0.01-0.16	0.74	0.06	0.05
									A4		0-92.2	0-1.1	0.01-0.18	0.80	0.04	0.02
B	79	25-852 (12.3,2) [#]	0.8-56.8 (5.51,2.11) [#]	0.8-56.8 (5.51,2.1) [#]	10 [@]	56-321 (-1.7,0.5) [#]	5.1-37.3 (0.03,0.07) [#]	9.2-56.8 (3.5,1.7) [@]	B-Source	10	0-1715	0-13	0.02-0.38	443.8	22.48	0.94
									B-13	8	0-506	0-4	0.1-0.3	2.59	0.20	0.04
									B7		0-439	0-3.1	0.01-0.4	3.32	0.38	0.04

* A6 includes plots A-VFS-1 and A-VFS-3 (5.8 m long), A4 includes plots A-VFS-2 and A-VFS-4 (4.1 m long), B13: includes plots B-VFS1 and B-VFS-3 (13.4 m long) and B7 includes plots B-VFS-2 and B-VFS-4 (6.8 m long); ⁺ i_{30} : maximum 30-minute rainfall intensity; [#] Values in parenthesis are (kurtosis, skewness); [@] Estimated from various precipitation data sources as described in test.

The efficiency of reduction of water, sediments and particulate and dissolved phosphorus are shown in Table 5 and Figures 3 – 6.

Table 5. Trapping efficiency of runoff volume, peak flow rate, sediment, TP and DP obtained at the experimental field sites during the period January 2007 – April 2008.

Plot *	Area Ratio	Flow Volume	Peak Flow Rate	Sediment	TP	DP
		Mean±SE [#]	Mean±SE [#]	Mean±SE [#]	Mean±SE [#]	Mean±SE [#]
A6	2.5	0.95±0.03	0.88±0.06	0.92	0.90	0.59
A4	3.4	0.69±0.07	0.76±0.06	0.96	0.98	0.70
B13	3	0.89±0.5	0.89±0.05	0.97	0.89	0.18
B7	5.9	0.91±0.4	0.90±0.05	0.98	0.99	0.95

* A6 includes plots A-VFS-1 and A-VFS-3 (5.8 m long), A4 includes plots A-VFS-2 and A-VFS-4 (4.1 m long), B13: includes plots B-VFS1 and B-VFS-3 (13.4 m long) and B7 includes plots B-VFS-2 and B-VFS-4 (6.8 m long);

[#] SE: Standard Error.

Generally, high reduction efficiencies of runoff, sediment and TP were observed at both

sites but this was much more variable for DP. This is expected since the filtering function of the dense vegetation relies on retardance of flow due to increase surface roughness at the filter. This produces a reduction in flow transport capacity of particulates (sediment and TP-apatite particles in sediment). In contrast, DP is removed mainly by infiltration during the short duration of a typical runoff event. Thus, higher DP reduction was observed for longer VFS that typically have more infiltration capacity than the contributing source areas. This illustrates the complexity of factors controlling filter efficiencies for different types of pollutants and local site conditions.

Comparison of results with previous 2006 study

For Site A (River) the filter efficiencies obtained in this report closely match and confirm those obtained in the previous 2006 study (Muñoz-Carpena et al., 2007). VFS runoff volume reduction efficiencies reported for plots A6 and A4 were similar, 0.86 and 0.67 respectively (Fig. 3). Sediment and TP removal for both studies were also close, above 0.9 (Fig. 4 and 5), and DP removal efficiencies were also lower than 0.70 in both studies although somewhat lower for plot A6 (Fig. 6). In general, filter length in general shows a clear trend in terms of reduction of runoff volume. This is clearly seen in Site A (Fig.3), with increased efficiencies for the longer filters.

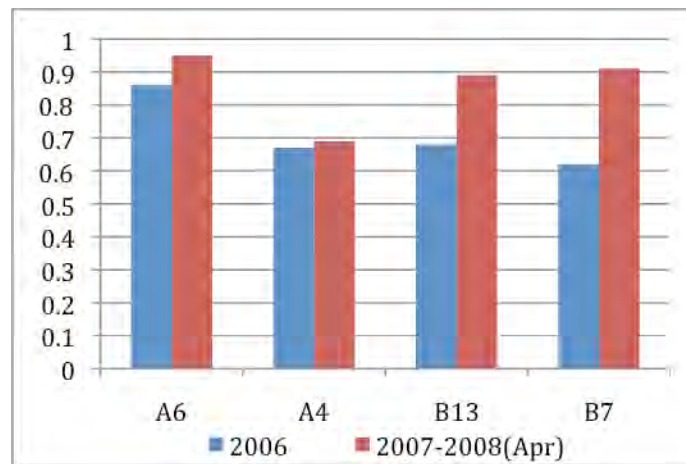


Figure 3. Flow volume removal efficiency of VFS during the period 2006 – 2008 (April)

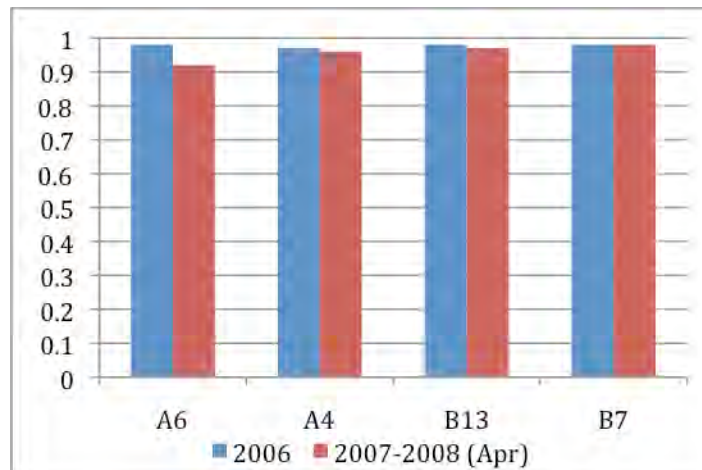


Figure 4. Sediment removal efficiency of VFS during the period 2006 – 2008 (April).

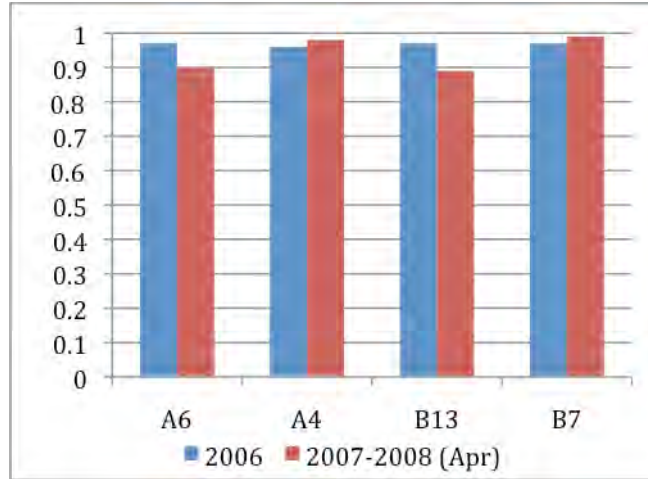


Figure 5. Total Phosphorus removal efficiency of VFS during the period 2006 – 2008 (April).

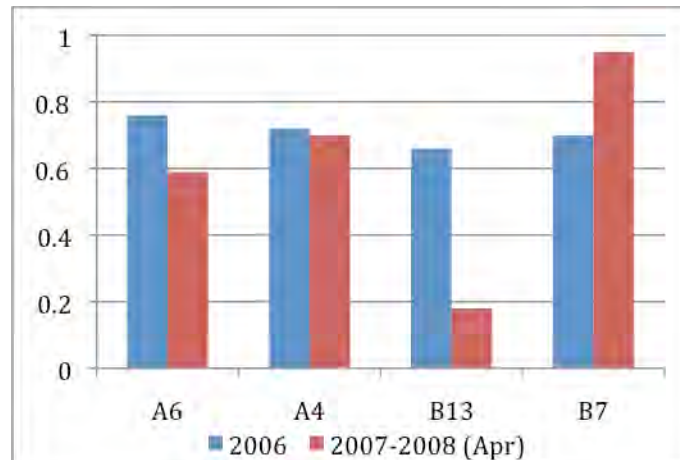


Figure 6. Dissolved Phosphorus removal efficiency of VFS during the period 2006 – 2008 (April).

Results for the Hill B (River) were also similar between the two studies in terms of filter reduction of particulates (sediment and TP) (Fig. 4 and 5). Dissolved phosphorus was found different at this site (Fig. 6), especially at B13. This large difference is likely related to the data gaps for these plots due to maintenance and equipment malfunction. It is expected that the data collected through the end of summer 2008 (rainy period) will match the trends observed in the previous study.

It is interesting to note that the trapping efficiencies of particulates obtained for the different site characteristics are relatively insensitive to area ratios (source/VFS). The reason is that in general all filters tested achieved a maximum practical removal efficiency and that shorter filters would have been needed to capture some sensitivity to filter length. Previous authors have shown that for coarse size particles, only a relative section at the front of the filter is active in the process and retains most of the material, so that longer filters will not typically show any benefits. However, the longer filters do increase trapping of fine particles like clays. Since the bulk of the sediment (and related TP) in our experimental sites (sand tailings) is of the coarser size, our results

confirm the insensitivity of the filter to longer lengths. In practice, shorter filters than 4 m are likely not present in field situations, so the results indicate that relatively small areas dedicated to this BMP at the bottom end of the sand tailings slopes will likely suffice to retain particulate pollutant transport with runoff.

As indicated above, more complex factors related specific soil characteristics at each site drive the DP removal efficiency, although in general this efficiency will be significantly lower than that for particulates (Kuo at al., 2008). This efficiency could be enhanced by practices that increase P retention at the filter, like various types of surface soil amendments, or increase infiltration in the filter. However, research should be conducted to assess the practicality and improvement that this practices would introduce.

Future Steps

As a result of the existing field and modeling research, the FDEP-BoMR is confident that VFS are an effective BMP to control phosphorus runoff pollution control and that the VFSSMOD-W/BMP combination will provide a basis to develop functional guidelines that can be used in a regulatory and after-regulatory manner. Given that "...there is no standardized width for regulating all potential impacts on ecological and hydrological functions provided by buffers" (pg. 39, Peace River Basin Resource Management Plan), there is a critical need for the FDEP to develop functional guidelines on the design, installation and maintenance of VFS in the reclaimed mining areas. A new collaborative research proposal between FDEP-BoMR and UF is being prepared to seek funding from the Florida Institute of Phosphate Research (FIPR, <http://www.fipr.state.fl.us>). The overall goal of the new proposed project is to inform the development of a code of practice to design, install and maintain VFS as an effective BMP for reclamation of phosphate mining areas. To fulfill this goal, we plan to pursue following specific objectives:

1. Determine the optimal VFS design parameters (e.g. filter width and structure) necessary to meet surface water federal (TMDL), state (Rules) and local (Ordinances) environmental standards based on site-specific characteristics (% clay in refuse materials in the tailings, slope length and angle, vegetation types, design storms) for reclaimed phosphate mining areas.
2. Quantify the risk levels of VFS performance (in terms of uncertainty of expected total sediment and phosphorus runoff loads removal by the filter) for varying local conditions, design features and maintenance practices. This uncertainty/risk goal will allow optimal sizing of VFS features for exploration of environmental management/permitting scenarios.
3. Working closely with FDEP/BMR, integrate the model results and "risk of performance" information into design, installation and maintenance guidelines to aid in the FDEP formulation of codes of practice.

The successful completion of the proposed project will inform science-based codes of practice used by the environmental management and permitting agencies to control runoff and P transport from reclaimed phosphate mining areas.

We plan to use field-tested modeling and uncertainty/risk analysis tools to assist FDEP/BMR and related agencies in the development of a code of practice to design, install and maintain VFS for reclaimed phosphate mining areas. Our methodology is to utilize existing GIS land-use characteristics and surveys of the mining areas in conjunction with the mathematical model VFSSMOD-W to compile an extensive database of optimal site-specific VFS design parameters required to meet desired surface runoff phosphorus and sediment load reductions. The exhaustive analysis will incorporate a formal estimation of the uncertainty associated with the performance of the VFS under the desired conditions, including screening and variance-based global sensitivity analysis, and pseudorandom multivariate-sampling for global uncertainty analysis.

The resulting database and uncertainty estimates will be used as a basis to construct simplified technical guidelines and design tools for the implementation of VFS. In close discussions with our project partner, FDEP/BMR, and other related agencies, we will develop VFS performance tables, design nomographs, and a risk/uncertainty report to provide technical

support FDEP VFS codes of practice. In addition, we will construct a web-based tool for engineers and planners to simulate site-specific features of VFS performance and optimize their design to achieve desired target reduction of sediment and TP in the Basin.

References

- Kuo, Y.-M., R. Muñoz-Carpena and Y. Li. 2008. Runoff Water Quality Pollution from Reclaimed Phosphate Mining Sand Tailings and Control by Vegetative Filter Strips. J. Environ. Qual. (Q08-0249, May 2008).
- Muñoz-Carpena, R., Y.-M. Kuo and Y. Li. 2007. Using vegetative filter strips to reduce phosphorus runoff transport from reclaimed phosphate mining areas in Central Florida Final Project Report to the Florida Department of Environmental Protection-Bureau of Mine Reclamation, DEP contract No. SP633. August 2007. University of Florida: Gainesville. http://carpena.ifas.ufl.edu/Publications/UF_VFSReport.pdf

LIST OF APPENDICES

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2. Remote access to dataset in HydroBase server

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APPENDIX I: Data set in electronic format

CD contents

The enclosed CD contains this report in electronic format and a Directory “Data”. This directory contains the data collected during the experimental period in the electronic formats described in this Appendix 1.

Raw Data (Text Format)

Rain, runoff flow rate and soil moisture are collected by a data logger on each site (River or Hill). Summaries of each of those parameters are collected by the system every 30 minutes. If flow in the flumes or rain is detected by the probes, readings are stored every minute. Soil moisture is always stored every 30 minutes. Raw data is downloaded as a text file from the field data logger. Every line of the file contains a code number (array), which describes different parameters. The codes used are described in Table I.1. In each site, sixteen probes record the values of flow in flumes (8) and soil moisture (8) across source areas and vegetative filter strips.

Table I.1. Code description of the data collected by the data loggers located in the field sites.

Code Number (array)	Description
110	Initialization used
114	Rainfall data. Units in minutes
115	Cumulative rain (in mm) and average soil moisture (voltage, in mV) recorded every 30 minutes. Data range of voltage (moisture) should be between 256 and 950.
116	Flow rate averages for flumes in liters per minute recorded every 30 minutes. The data should be around 2.3 (no flow) and 444 (water level 6 inches) L/min.
101-106	Sampler records with flow flumes based on sample-number dependent on sampling increment. The fifth column is cumulative flow depth. Every field site has 6 samplers, two located in the centered plots and four in the VFS, one per each VFS plot.
201-208	Hydrograph outputs based on output increment. The fourth column is flow rate in L/min.
301-308	Zero flow average at start or reset.

Code number series 101-106, 201-208, 301-308 are based on the numbering of source areas and filter strips plots as shown in Table I.2.

Table I.2 Code numbering distribution in the source areas and VFSs.

Source Area	Code number (Array)			
		207 307	101 201 301	102 202 302
VFS	103 203 303	104 204 304	105 205 305	106 206 306

The array code in each line of the raw data file followed by the consecutive day of the year (Julian date), time and the corresponding data described in Table I.1. For simplification, data

have been processed and stored monthly in individual folders by site and year (i.e. Appendix1/text/SiteB2007/hAug2007.txt).

Processed Data (Spreadsheet Format)

Each raw data text file described above was processed into a MS-Excel spreadsheet file after parsing and separating the data into types as described in Table I.2.

Table I.3. Organization of text files in worksheets within a spreadsheet

Worksheet name	Description
Sheet 1	Contains all the data as they appear in the text file, but ordered in cells.
Rain	Contains data of rain in mm/min.
Soil Moisture	Contains data of cumulative rain each 30 minutes and the voltage recorded in soil probes in the source areas and vegetative filter strips. (This voltage is after converted to soil moisture)
Global Flow	Contains data of 30 minutes-average runoff in each flume (four in source areas and 4 in VFS). Starting value is around 2.3 L/min, but this value is re-set to zero and all the rest values are re-calculated when runoff volume is estimated.
Source Area A-D	Contains data of runoff in L/min for each source area (see Figure I.2)
VFS 1 – 4	Contains data of runoff in L/min for each VFS (See Figure I.2)

For all the worksheets (one per each month per year), the code number, day (consecutive) and time precede the corresponding information detailed in Table I.3 and I-4.

Table I.4. Flow connectivity between source and filter area plots. The column on the right represents the VFS that receives runoff from each of the source areas.

Field plot	VFS
Source Area A	VFS 1
Source Area B	VFS 2
Source Area C	VFS 3
Source Area D	VFS 4

Information of the /SiteA2008 and /SiteB2008 folders contain information from January – April 2008. Folder /SiteA2007 and /SiteB2008 contains 12 files each one, one per every month of the year.

Remote access to dataset in HydroBase server

Description of HydroBase

The final processed data has been stored and made available to FDEP-BoMR at UF-HydroBase, a web-based information system for hydrological data storage, maintenance and mining. HydroBase is based on industry-standard Microsoft SQL server, .NET asp web services, and Java. The application contains powerful on-line web-based graphing, statistical analysis, and reporting capabilities as well as project maintenance and administration. Access to this system allows the District personnel quick analysis of the project data in the form of graphs and statistical tables.

The “project-based” logic model used by HydroBase closely matches research and environmental monitoring environments. Project team members on different roles (PI, collaborator, general public) can remotely assess and administer the on-line database through a complete web interface. Projects can be maintained private (for team members only) or public (open data sources). When users participate in different projects, they can work on specific

